CONTROLLING OF NONLINEAR SYSTEM BY USING FUZZY LOGIC CONTROLLER

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Abstract - ***This paper presents the control of nonlinear system by using fuzzy logic controller. In order to synthesise a control system both the controller selection and adjustment of parameters plays an important role. PID controller is used in many industries, It doesn't give acceptable response or performance for system with uncertain time delays, performance and nonlinearities. Hence the parameters of PID controller are tuned to get satisfactory response. Therefore tuning of PID controller is done by Fuzzy logic. Fuzzy control establishes an intelligent control.***

Fuzzy logic control has been widely used for nonlinear higher order and time delay systems. Because of their Knowledge based nonlinear structural characteristics they are applied to nonlinear systems. Fuzzy controller can perform online and offline parameter operations. Fuzzy PID controller is designed by fuzzy control principals and techniques. Fuzzy plus PID provides good performance when compare to only fuzzy. For fuzzy controller simple rule base is used, whereas for Fuzzy PID different rule bases are used for proportional, integral and derivative gains to make faster response.

Key Words: *Fuzzy logic controller, PID controller, Nonlinear System, State Transition Algorithm, Genetic Algorithm, Particle Swarm Optimization.*

INTRODUCTION

PID controllers are the best known controllers used in many industrial processes because of simple structure and robust performance. PID controllers deal with both time and frequency responses if they are tuned properly. But for complicated systems the performance of conventional PID controllers are tend to degrade. The performance of the controllers changed drastically with the introduction of fuzzy logic controller. For wide range of industrial applications fuzzy logic controllers are being used. This fuzzy logic controller shows better performance when compared to PID controllers. The combination of both fuzzy and PID produces good performance. Fuzzy can be applicable to any system. A fuzzy logic controller makes control decisions by using If-Then rules.

After development of Fuzzy logic an important application was developed in control systems known as Fuzzy PID controllers. For solving nonlinear tuning problems, the design of Fuzzy PID controller remains a challenging area. For classic or modern control system applications, instead of PID controller a Fuzzy PID controller is used. They are used in converting the error between the measured and reference variable in to command. In practical design the information about input, output transfer characteristics must be known. The main purpose is to develop control system for all kind of process with higher efficiency.

The introduction of Fuzzy block in to the structure of linear PID controller resulted Fuzzy PID controller. Equivalence between Fuzzy PID controller and a linear control structure can be established by tuning method. The both input variables and control action are given in linguistic forms for Fuzzy PID controller. For conventional PID controllers Fuzzy logic provides a certain level of artificial intelligence. Fuzzy PID controllers provide self-tuning ability and online adaptation to nonlinear and time delay systems.

Fuzzy logic controller is classified in to two categories named Mamdani and Takagi-Sugeno. For making decisions mamdani type fuzzy logic controller uses fuzzy members. Takagi-sugeno type fuzzy logic produces control actions by linear functions of the input variables. Mamdani type of fuzzy systems gives some tuning guidelines and recommendations for increasing the quality of control systems. This is used to solve the problem of tuning of Fuzzy PID controller. For common structure of Fuzzy PID controller the transfer function and equivalence relations between controller parameters are obtained. A Fuzzy PID controller is designed to increase the system response in both transient and steady state when compared with individual PID Fuzzy controllers. In Fuzzy PID controller the parameters are tuned by using fuzzy logic controller in order to get satisfactory response.

Fuzzy PID controller is designed with integral and derivative control actions and set of 49 rules for improving transient and steady state responses for both first order and second order systems. For an industry contains a typical PID controller design. Parameters of that controller are tuned manually to achieve desired plant response. The manual tuning is replaced by fuzzy controller. It improves the system response. Fuzzy control system is an expert system applied to problem solving in control.

By linguistic variables fuzzy rules provides natural frame work for thinking and knowledge formation. Selection of input and output scaling factors plays most important role in design of fuzzy controller because of their significant effect in controller stability and performance. When compared to neural networks this method avoid delays associated with network training. There will be updating of rule base and membership function.

1.PID CONTROLLER:

It is a control loop feedback mechanism used in industrial control systems. PID controller is used to calculate the error value as taking the difference between the measured value and desired value. By adjusting the control variables the controller minimizes the error

The three basic behaviour modes that are used by the PID controller are P-proportional, I-integrate, D-derivative. Proportional and integrative modes are used as single modes whereas derivative mode is rarely used, but combinations of PI and PD are commonly used. PID controller is simplest possible on-off controller.

DESIGN OF PID CONTROLLER:

For estimation of nonlinear system model a PID controller is designed for stability and other performance. PID controller is widely used in industrial process.

The continuous form of PID controller is described as follows:

$$u(t)=Kp[e(t)+1/Ti\int_0^t e(t)\,dt + T_d\, d/dt\, e(t), \qquad (1)$$

Where

e (t) is the desired error signal between desired and actual outputs,

u (t) is control force

Kp is proportional gain

T_i is integral time constant

T_d is derivative time constant

The approximations are followed:

$$\int_0^t e(t)\,dt \approx T \sum_{j=0}^{k} e(j)$$
$$d/dt\, e(t) \approx (e(k)-e(k-1))/T, \qquad (2)$$

The sampling time period is T.

Equation (2) can be rewrite as

$$u(k)= Kp\{e(k)+T/T_i \sum_{j=0}^{k} e(j)+T_d/T[e(k)-e(k-1)]\}; \quad (3)$$

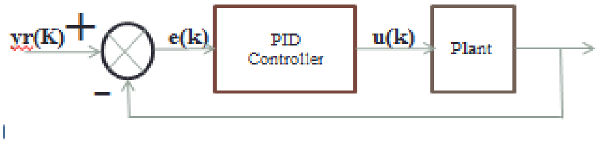

Figure 1: The design of PID controller

y_r (k) is the reference output

y (k) is the system output at the sampling point

PID controller is tuned to get fast response and to acquire good stability.

2. FUZZY LOGIC:

Fuzzy logic is a multi-value logic which allows some middle values define between conventional evaluations like yes or no, high or low, true or false. It is an expert system uses a collection of membership functions and rules. Fuzzy system contains membership function defined by the parameters. The degree of membership lies between 0 and 1.Triangular, Trapezoidal, Gaussian are membership functions.

The basic fuzzy model consists of fuzzification, Interface, defuzzification and knowledge base. The input to the system is crisp set. Fuzzification is nothing but conversion of crisp set to fuzzy set. In fuzzification membership function is applied and degree of membership is determined. The fuzzy interference process combines membership function with control rules to get fuzzy output and these outputs are arranged in tabular form called as look up table.

The process of producing quantifiable result in fuzzy logic is called defuzzification. It converts fuzzy set in to real numbers.

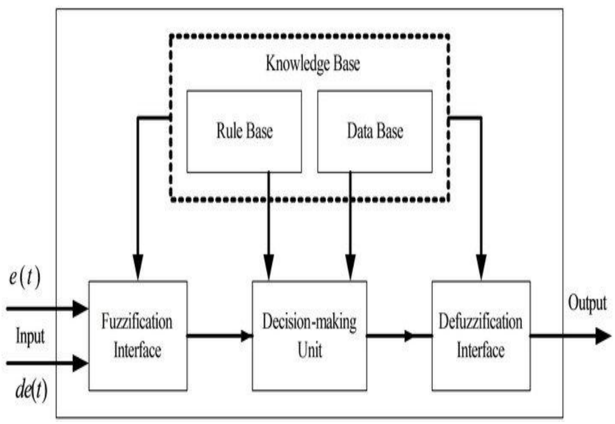

Figure 2: Block diagram of Fuzzy logic

3. FUZZY PID CONTROLLER:

For tuning the parameters of PID controller some conventional methods are carried out which have some limitations. An intelligent method presented in this paper is based on Fuzzy in order to tune the PID controller. If a system contains time delays, uncertain dynamics and nonlinearities, the conventional PID controller doesn't give acceptable performance. Hence the parameters of the PID controller are tuned in order to get satisfactory response. Fuzzy logic is used to tune the PID controller automatically. Fuzzy system transforms a linguistic control strategy in to an automatic control strategy based on expert knowledge. Figure 3 shows the block diagram of Fuzzy PID controller. Fuzzy logic tool box in MATLAB is used to implement Fuzzy PID controller.

The error e (t) and rate of change of error Δe are the inputs to the controller. While the outputs are controller gain Kp, Ki, Kd, its structure is to input, three output structures. The range of input and output membership function is to be determined. The linguistic variables are assigned as NB, NM, NS, Z, PB, PM, PS. The membership functions used are Gaussian, Triangular, Trapezoidal and Bell curves. Fuzzy rule base consists of If-Then rules, which represents the knowledge level and human abilities which adjusts the system for minimum error and fast response. Fuzzy consists of two models named as Mamdani and takagi-Sugeno model. Fuzzy control system is an expert system applied to problem solving in control.

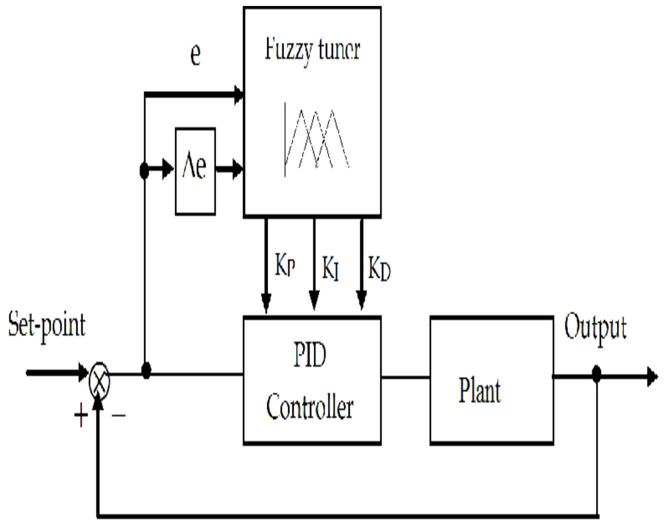

Figure 3: Fuzzy PID controller Block diagram

e: error signal
Δe: change in error signal
Kd : Derivative gain
Kp : proportional gain
Ki : Integral gain

4. STATE TRANSITION ALGORITHM:

The process of tuning a system from one state to other state is called state transition. It is described as state transition matrix. State transition matrix has greater importance in modern control theory and also in communication theory. STA deals with state, state transition. A solution can be regarded as state and updating solution can be treated as state transition. Four special operators are created to solve the optimization problems.

They are
Rotational transformation (α)
Translation transformation (β)
Expansion transformation (γ)
Axesion transformation (δ)
State transition algorithm is used to tune the PID controller parameters.

ALGORITHM:

1. Repeat
2. If $\alpha<\alpha_{min}$ then
3. $\alpha \leftarrow \alpha_{max}$
4. End if
5. Best ← Expansion (funcfcn, Best, SE, β, γ)
6. Best ← Rotation (funfcn, Best, SE, α, β)
7. Best ←Axesion (funfcn, Best, SE, β, δ)
8.$\alpha \leftarrow \alpha/f_c$
9. until the maximum iteration is met.
f_c is constant coefficient.

5. GENETIC ALGORITHM:

Genetic algorithm is used to tune the parameters of the PID controller. Genetic algorithm not only manipulates one potential solution to a problem but a collection of potential solutions. This is called as population. The potential solution in the population is called chromosome. These chromosomes are encoded by the parameters of the solution. Each chromosome is compared by the other chromosome in the population and rated according to fitness. Population is also called as mating pool, represented by binary or real coded values.

Creation of new chromosome from the existing chromosome can be done by merging the existing ones or modifying them. Reproduction can be done by Roulette wheel method. The two genetic operators are cross over and mutation. Cross over operator recombines the obtained information in to workspace. Mutation operator generates new genes to ensure exploration. By this premature convergence can be avoided.

ALGORITHM:

1. Initialize Population
2. Evaluate their fitness
3. Select the fittest member of the population
4. Reproduce using probability method
5. Implement crossover operation on the reproduced chromosome
6. Execute mutation operation with low probability
7. Repeat step 2 until predefined convergence is met.

6. PARTICLE SWARM OPTIMIZATION:

Particle Swarm Optimization optimises the problem by considering population of solution. The particles move in the search space with some velocities. Each particle move is influenced by the local best position. PSO is a pattern search method which does not use the gradient of problem that is being optimized. That means it does not require the optimization problem. It is a simple algorithm. For a number of iterations, a group of variables adjusted very close to the member whose value is closest to the target at any position.

ALGORITHM:

1. Initialise each particle
2. Calculate the fitness value of each particle
3. If the fitness value is better than the best fitness value in the history, then set the current value as the new P_{best}
4. Choose the particle with the best fitness value of all the particles as the g_{best}.

SIMULATION RESULTS AND COMPARISION:

For controlling Nonlinear system a fuzzy logic controller is utilised in order to give good stability and performance. In order to implement Fuzzy PID controller fuzzy logic tool box is used in MATLAB. In this paper the following to insistences are studied.

EXAMPLE 1: An unstable system is described by

$x_1(k+1) = \theta 1 x_1(k) x_2(k)$, $x1(0)=1$,

$x_2 k+1) = \theta 2 x_1^2(k) + u(k)$, $x_2(0)=1$,

$y(k) = \theta 3\, x_2(k) - \theta 4\, x_1^2(k)$,

The real parameters of the nonlinear system are assumed to be $\theta = [\theta 1, \theta 2, \theta 3, \theta 4] = [0.5, 0.3, 1.8, \text{and } 0.9]$.
The relative variables used in the Fuzzy PID are as follows $\theta\,1 €[0,2]$, $\theta 2 €[0,2]$, $\theta 3 €[0,2]$, $\theta 4 €[0,2]$, N=8.

For Fuzzy PID controller:

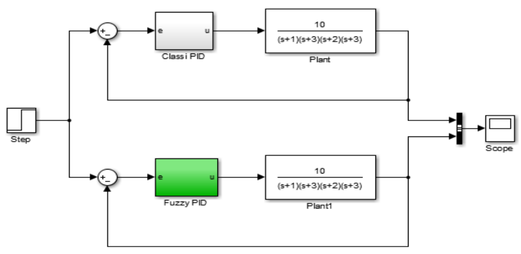

Figure 4: PID controller design by using Fuzzy logic controller for example 1

For fuzzy PID

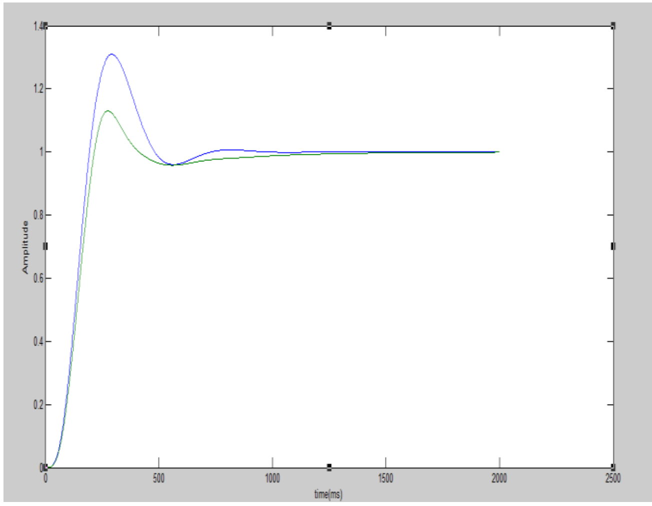

Figure 5: Comparison graph between Fuzzy PID and normal PID for example 1

Blue line represents fuzzy with PID which provides better optimisation

Green line represents normal PID response that is not better than Fuzzy PID

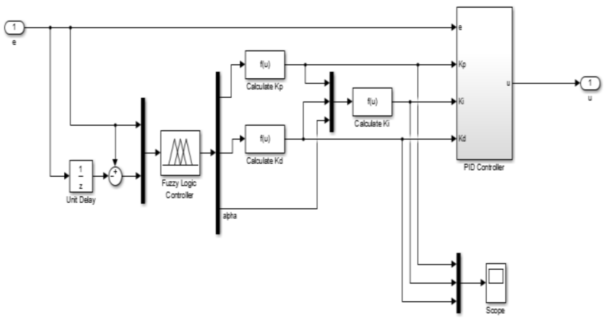

Figure6: PID controller optimization using Fuzzy logic controller

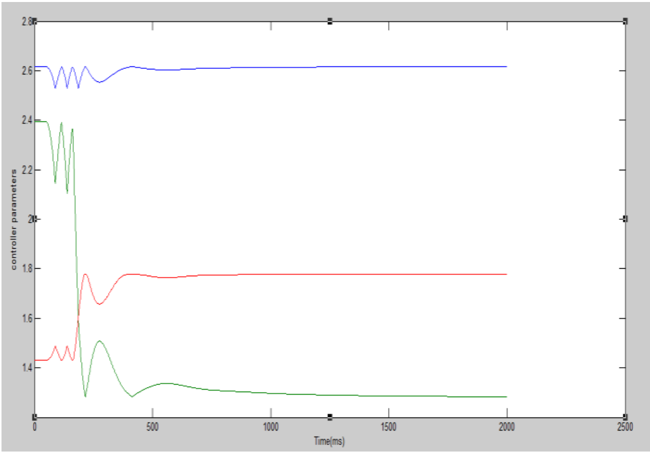

Figure 7: Kp, Ki, Kd simulation graphs for example

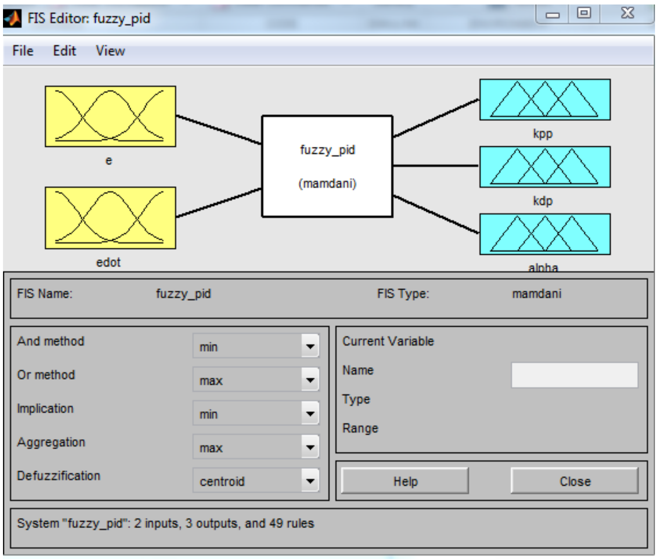

Figure 8: FIS Editor of Fuzz PID

The model used here is Mamdani model.

For State Transition Algorithm:

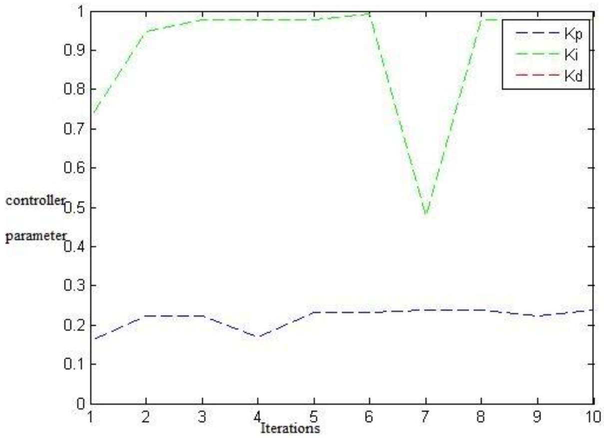

Figure9: Kp, Ki, Kd graphs of STA

For Genetic Algorithm:

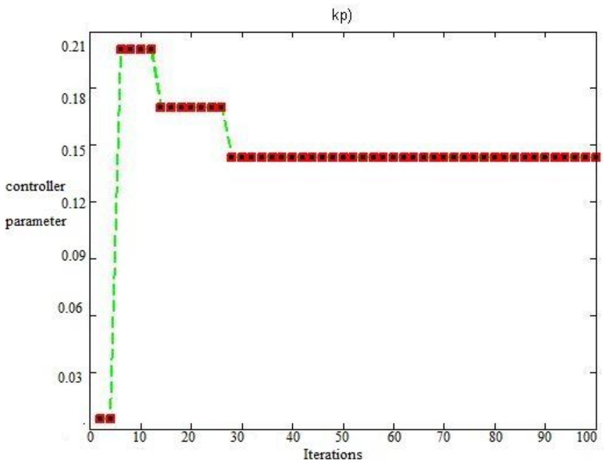

Figure 10: Kp graph of GA

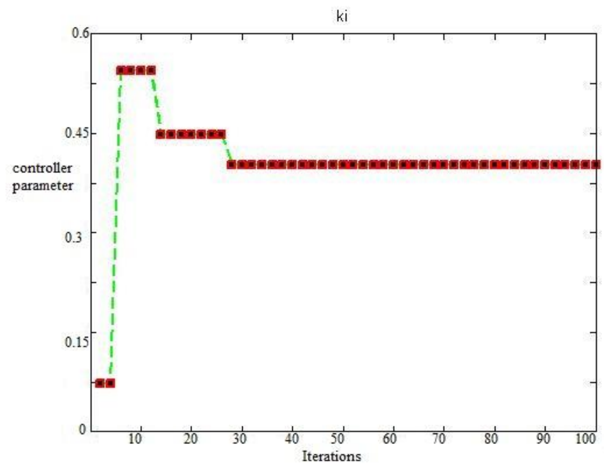

Figure 11: Ki graph of GA

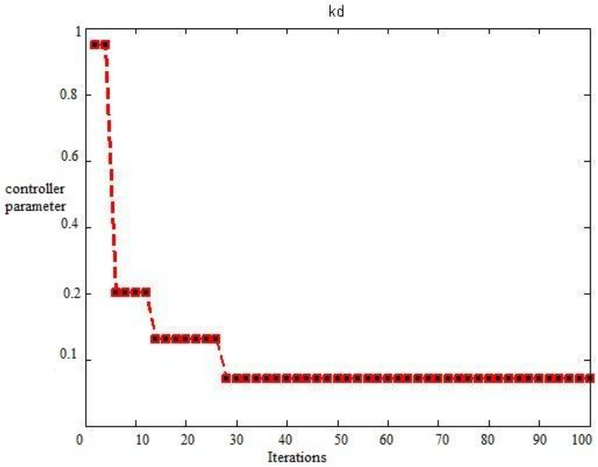

Figure 12: Kd graph of GA

For Particle Swarm Optimization:

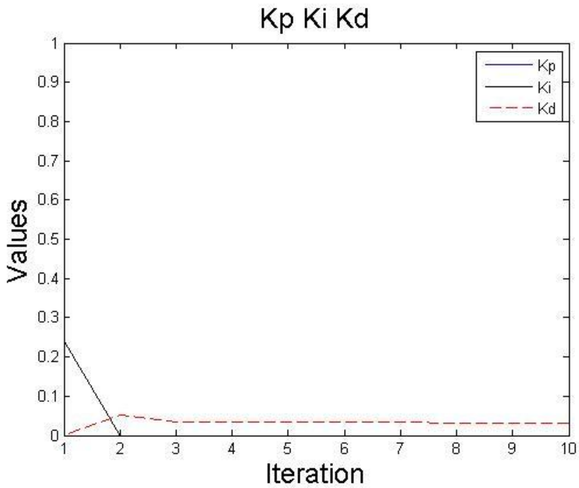

Figure 13: Kp, Ki, Kd graphs of PSO

Table 1: Best parameters of PID controller for example 1

Algorithms	**Kp**	**Ki**	**Kd**
Fuzzy PID	1.6409	1.118	2.09
STA	0.23	0.9	0
GA	0.15	0.34	0.1
PSO	1	0.2814	0

EXAMPLE 2: Consider a first order with time delay system whose transfer function is given as

$G(s) = y(s)/u(s) = (k/Ts+1)\, e^{-ts}$,
K is the steady state gain
T is the time constant
t is the time delay with sampling time 0.01
The actual numerical values are K=10, T=5, t=9.

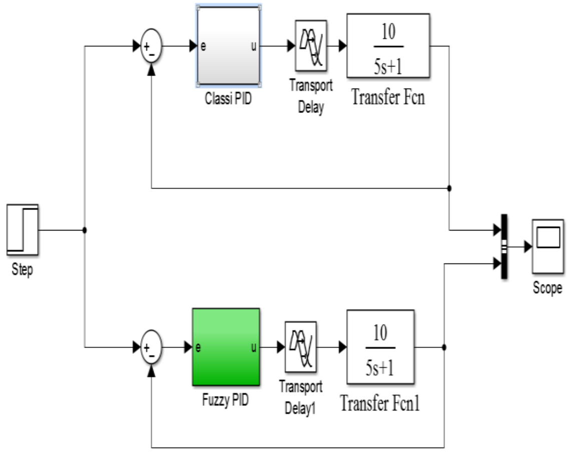

Figure 14: PID controller design by using Fuzzy logic controller for example 2

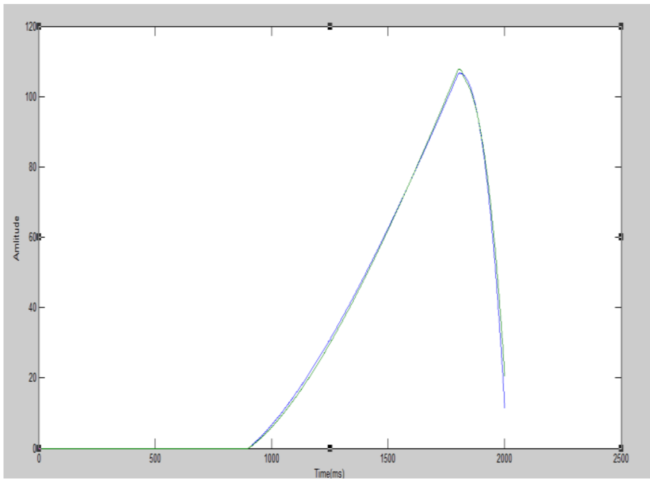

Figure 15: Comparison graph between Fuzzy PID and normal PID for example2

Blue line represents fuzzy with PID which provides better optimisation

Green line represents normal PID response that is not better than Fuzzy PID

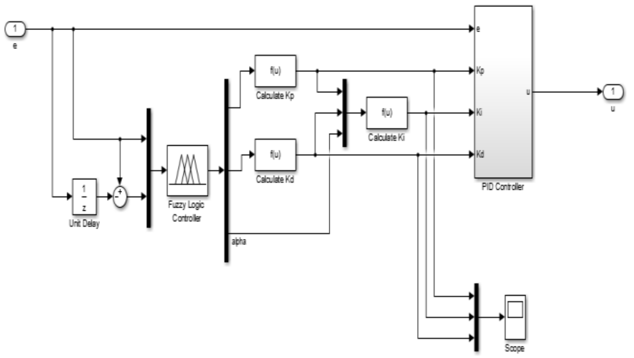

Figure 16: PID controller optimization using fuzzy logic controller

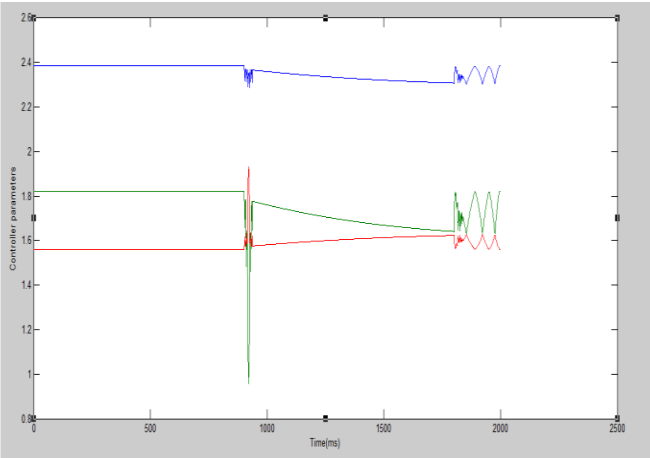

Figure 17: Kp, Ki, Kd simulation graphs for example2

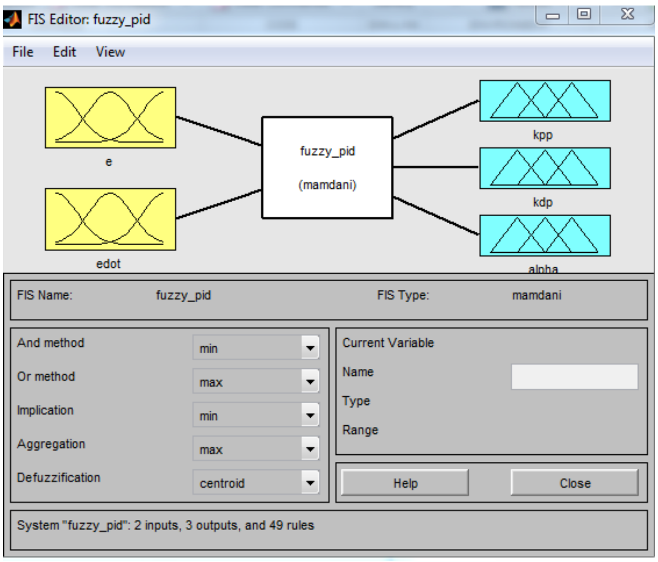

Figure 18: FIS Editor of Fuzzy PID

The model used here is Mamdani model

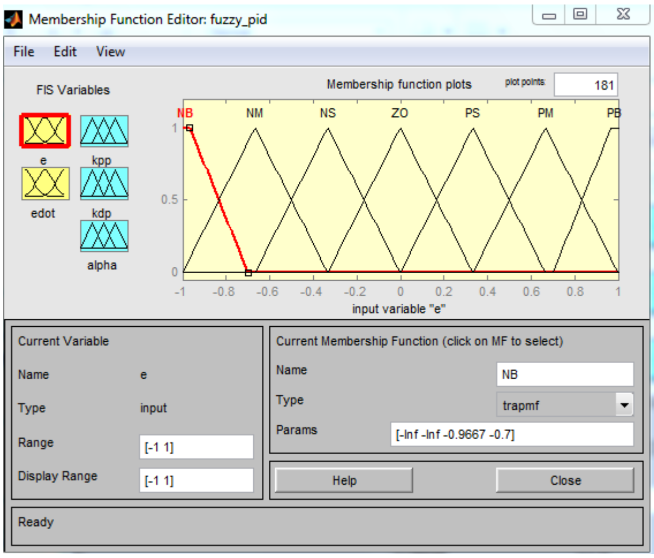

Figure 19: Membership function editor of Fuzzy PID

FOR STATE TRANSITION ALGORITHM:

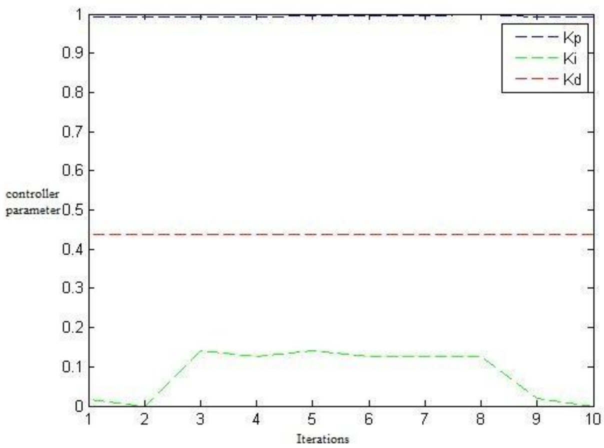

Figure 20: Kp, Ki, Kd graphs of STA

FOR GENETIC ALGORITHM:

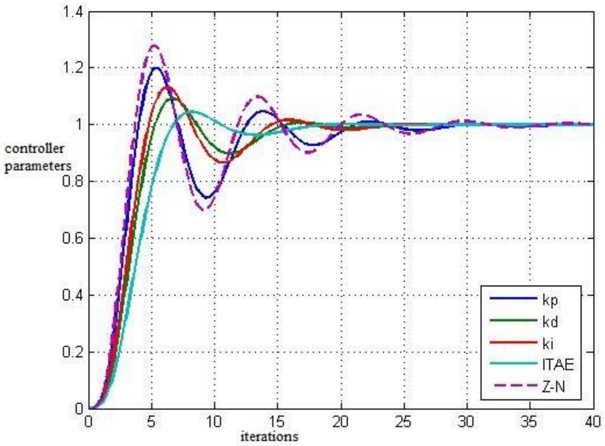

Figure 21: Kp, Ki, Kd graphs of GA

FOR PARTICLE SWARM OPTIMIZATION:

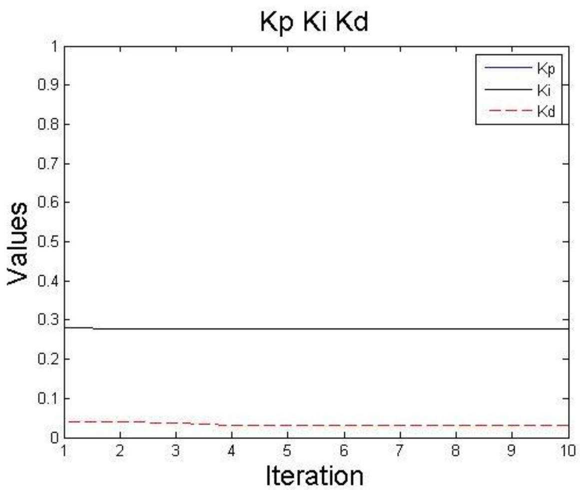

Figure 22: Kp, Kd, Ki graphs of PSO

TABLE 2: Best parameters of pid controller for example 2

ALGORITHM	Kp	Ki	Kd
FUZZY PID	1.496	2.28	1.218
STA	0.9	0.438	0.014
GA	1.19	1.13	1.09
PSO	1	0.24	0.05

CONCLUSION:

In this paper a new optimization method named Fuzzy logic controller is used to solve the problem of controller design for nonlinear systems. As an optimizer, Fuzzy logic controller is used to achieve accurate model, and then it is adopted to obtain offline PID controller. Fuzzy logic controller is used to tune the parameters of PID controller in order to get good performance and also to control the nonlinear system. Fuzzy with PID provides better optimization when compared to other optimizations. This optimization maximises the efficiency of production. By comparison with STA, GA and PSO it is found that Fuzzy PID is more stable. With regard to convergence rate, it is also discovered that Fuzzy PID is much faster than its competitors.

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